Impacts on the IXO Observing Efficiency

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ABSTRACT

The International X-ray Observatory (IXO) has a top level requirement that the observing efficiency be 85%. This is a challenging requirement, given that the observing efficiencies for CXO and XMM-Newton are between 60% and 70%. However, the L2 orbit for IXO means that it will not be subject to the earth block/radiation zone effects that are seen for CXO and XMM-Newton. Outside of these effects the efficiencies for CXO and XMM-Newton do approach 85%, so this requirement appears achievable for IXO. In this paper we itemize the effects which impact the observing efficiency, in order to guide the design of the observatory. Meeting the 85% requirement should be possible but will require careful attention to detail.

Keywords: X-ray, Observation Planning, Future Missions

1. INTRODUCTION

In this paper we aim to capture the design considerations for the International X-ray Observatory (IXO) which may effect the science observing efficiency. We use existing X-ray observatories, mainly the Chandra X-ray Observatory (hereafter CXO) and the XMM-Newton (hereafter XMM) observatories as guides. An essential pre-requisite for this study is an observing plan (target list) which we have assembled based on the science objectives laid out in the ASTRO2010 and Cosmic Visions 2015 submissions from the IXO team. We note that it is 'cost effective' to maximize the observing time, as a 1% change in observing efficiency per year equals 300 ksec/year, or US$6M/year assuming a US$3B mission with a 5 year lifetime.

1.1 Definitions

Observing Efficiency: The fraction of the total 'good time' spent observing science targets versus all potential observing time. Times when the observatory must be shut down (radiation zone passes, for example) are not counted as potential observing time. The IXO will be stationed at L2 where there will be no radiation zone passes or earth occultations, so potential observing time is simply clock time. Good time includes Guest Observer (GO), Guaranteed Time Observer (GTO), Director's Discretionary Time (DDT), Targets of Opportunity (TOOs) and astronomical calibration targets. Not-good time includes time spent in slewing, instrumental setup, telescope settling, momentum management, spacecraft or instrumental issues, or time lost due to background flares that shut down the observatory. Observing time that later proves to be contaminated due to slightly increased backgrounds does count towards the good time observing efficiency.

Calibration time: Time spent either observing standard astronomical calibration targets (such as supernova remnants, stars, or binary systems) or solely observing internal calibration sources with no data from an astronomical source. The former is counted towards observing efficiency, as it has potential science uses, while the latter does not.

TOO: Target of Opportunity. An observation target not part of a long-term plan, but observed due to a sudden change. Typical X-ray TOOs include AGN flaring, X-ray binary flares, gamma-ray bursts, supernova explosions, and novae. These typically come in multiple categories, including targets that must be observed within 24-48 hours to be useful and those that must be observed within 4-7 days or within 7-31 days. The shortest response TOOs are typically called 'fast TOOs.'

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1.2 Previous Missions

For CXO and XMM, which are in long elliptical orbits around the Earth, the perigee periods spent below the Earth's magnetosphere are not potential observing time; see Table 1. It must be noted, however, that due to differences in definitions and approach direct comparisons between CXO and XMM are difficult if not impossible; the comparisons in this document are intended to show plausible ranges in existing missions. For example, XMM loses otherwise usable observing time because of the need to use ground stations in support for launches and early orbit operations of other missions.

Table 1: Aspects of Observing Efficiency

	Chandra	XMM-Newton	IXO
% of time potentially usable	~75%	~78%	100%
% of above used for science (*Observing Efficiency*)	~94%	~78%	85%
Total % Science Time in a calendar year	**~70%**	**~61%**	**85%**

2. Impacts on Observing Efficiency

As a large astronomical spacecraft at L2, IXO may be subject to impacts on observing efficiency at different levels than X-ray satellites in LEO or large elliptical orbits. However, in general these impacts are not unique to IXO, allowing comparison to existing missions such as CXO and XMM. We have therefore assumed here that CXO and XMM are reasonable proxies for most of the potential impacts, such as average slew angles and TOOs, while also pointing out those areas (such as solar flares) that could be significantly different for IXO.

With this assumption noted, we have identified a number of potential impacts on observing efficiency that should be minimized to the extent possible. These include:

1. Slew time – The time spent moving from one target to the next.
2. Telescope settling – Delay after reaching a target until the telescope pointing is stable.
3. Instrument setup/calibration – Time spent preparing an instrument to begin operations. This includes, for example, recharging the dilution refrigerator (ADR) for the X-ray micro-calorimeter spectrometer (XMS), measuring dark current, and turning on high voltages.
4. MIP (movable instrument platform) translation – Time spent moving an instrument into the focal plane. CXO translates its instrument platform during slews to minimize its impact; XMM is observing with all instruments at the same time.
5. Engineering – Time spent for engineering purposes such as uploading commands, measuring aspect camera dark currents, or calibrating gyroscopes. Unlike CXO or XMM, where this could potentially be done during perigee pass, IXO will have to charge this time against observing efficiency.
6. Momentum Management – Time spent on momentum unloads of reaction wheels.
7. Other – Time lost due to issues internal or external to the mission:
    a. Spacecraft
    b. Instrument(s)
    c. Ground station
    d. Communication
    e. Solar flares
    f. Eclipses (Not relevant for IXO orbit)
8. TOOs – Both fast and slow TOOs may impact observing time as the planned optimal sequence of observing is interrupted.

Some of these operations may be done simultaneously, therefore 'hiding' their effect. For example, if they take less time than a slew, the MIP translation, ADR recharge, and momentum management might be done during the slew. Slew time and settling, however, are by their nature serial operations. Below we expand on several of these possible impacts.

2.1 Slew Time/Length

While the slew length (and therefore time) between targets should be minimized in order to increase observing efficiency, experience from CXO and XMM indicates that the average distance between targets is likely to be longer than calculated by searching for the nearest neighbor target. This is due to a variety of reasons, including time constraints placed on the observations in order to enhance the science return, the need to operate within spacecraft constraints (ie, solar pitch angle limits, thermal limits), and the need to regulate the use of any on-board expendables (ie, RCS gas, MIP translations). As these constraints are not yet well known for IXO, comparison to CXO and XMM are useful. A nearest neighbor calculation does however set a robust lower limit.

For this purpose, we used a sorted list of CXO observations from CY2003. The complete list includes ~1200 distinct 'observations,' although it should be noted that individual science observations could have been split in this list due to perigee pass, solar flares, or simple rastering. While instructive, the CXO satellite is not a perfect match to the IXO characteristics. CXO allows for any pointing angle that is more than 45 degrees from the Sun, while the IXO requirement is for a narrow 20 degree range around 90 degrees from the Sun. This additional flexibility, however, does not obviously indicate that the CXO slew angles will be larger or smaller than IXO's. XMM's pointing requirements are very similar to IXO's, and a separate study[1] which removes the effect of radiation zone passages finds an as-executed average slew distance of 48.3 degrees, and a great circle distance of 33.7 degrees.

The choice of CY2003 for this study was deliberate, as currently CXO observing is done to address thermal issues with little to no concern for minimizing slew angle. However, in CY2003, minimizing slew angle was a concern for the team, as one of a number of constraints. Input for this study was the CY2003 observation list, in observed order, containing target RA/DEC and slew angle to target. The list contains numerous slews that are either identical to zero degrees or anomalously small. The zero degree slews are due to contiguous observations of the same target that were interrupted by (for example) a change in the instrument set up and were therefore excluded from further consideration. Anomalously small (but non-zero) slews were due to 'raster scans' of a single object, so all slews <2 degrees have also been excluded. Note that the observing plan (described below) does not identify which observations may be raster scans and instead treats them as a single observation, so excluding rasters for this study is justified. We then compared three different slew angle histograms in Figure 1.

1) The actual slew angle as performed. Even for two observations pointed in the same direction this can be non-zero, as CXO is re-pointed during perigee pass and then returned to the target right before emerging from the radiation belts. Since no data can be taken while in the belts, this does not impact CXO's observing efficiency. Solid line.
2) The slew angle mathematically calculated using the previous pointing and the current pointing. This avoids any issue of perigee passages and similar considerations. Dotted line.
3) The slew angle if the observations were done in RA order. This is not the minimal solution – which would require solving the travelling salesman problem – but it is a reasonable approximation to one. Dashed line.

Figure 1 also shows that the average slew angle for the solid and dotted lines are nearly identical at 63 and 60 degrees respectively. However, the RA-ordered average is 37 degrees (compare to 33.7 degrees for XMM above), suggesting substantial savings if this kind of observation plan is allowable.

The CXO observation planners also noted that the schedule includes up to 15% of 'constrained' targets according to the Call for Proposals, but in fact this regularly increases to 25% for a number of reasons, while soft constraints requested by proposers and generally followed increase this value to 33-40%. For XMM, ~40% of the observations have some kind of time constraint. We assume that IXO will have a similar number of time constraints and therefore that the average slew distance is likely to be ~60 degrees. The IXO studies to date have considered slew rates ranging from 1 to 2 degrees/min. The rate for CXO is 2 degrees/min, for XMM is 1.5 degrees/min. We therefore budget a slew time of 1.68Ms (5.3% of the year) assuming the 1.5 degree/min rate, 60 degrees, and 700 targets, and note that the likely range is 4% to 8% of the year.

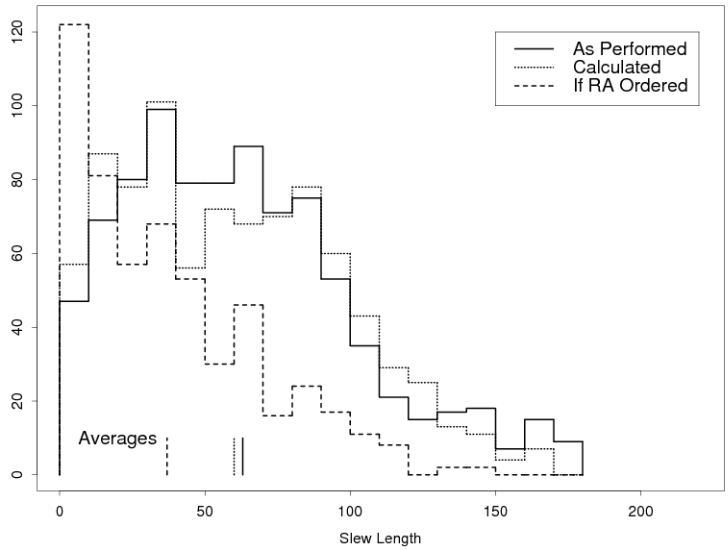

Figure 1: Histogram of CXO Slew Angles excluding slews less than 2 degrees. The 'calculated' angles may be more appropriate than the 'as performed' because there will be no radiation zone passages at L2. The 'if RA ordered' histogram has a smaller average slew length, but may not be achievable. It does however set a lower limit.

2.2 Telescope Settling

CXO allows 300 seconds for telescope settling, but this typically takes 200 seconds. This time includes allowing a 'ringing out' of structural vibrations in the observatory and also allowing the star camera to lock onto guide stars and track them, and for the Kallman filter to be initialized. For IXO, this ring out is expected to take <1 minute. Because aspect systems typically use a running Kallman filter to determine position, there will always be a delay on order of the filter time before the aspect knowledge meets requirements. We therefore budget a settling time of 140ks (200sec x 700 observations) or 0.4% of the year.

2.3 Instrument calibration/setup, ADR Recharge

Calibration time, spent observing astronomically interesting objects, ranges from 2% for CXO to 5% for XMM. The number of instruments on IXO is closer to the number on XMM than CXO, so we assume 5% calibration time. For the majority of instruments the setup times are much less than the probable slew times and the setup can therefore be done during the slew, adding no additional efficiency hit. The exception is recharging the XMS/ADR. There are a variety of ADRs which might be used with the XMS, with a range of 'recharge' times. During recharge the XMS cannot be used for observations. The requirements for the ADR are that it can hold for 31 hours and that the recharge time take less than 10 hours. If the recharge time is >1 hour one would slew to another (non XMS) target during the recharge, so we will assume the every XMS observation >31 hours will result in an additional slew. There are 38 observations in the year long target list with exposure times >31 hours, but only 7 of these use the XMS as the prime instrument. These additional 7 slews will require 16.8ks at the 1.5 degree/minute slew rate. We therefore budget 16.8ks, or 0.05% of the year, for ADR recharge, and note that the range is 12.6ks to 25.2ks.

2.4 MIP Translation

These will normally occur during slews. There may be occasions where a single target is to be observed by multiple instruments, for example, a bright black hole x-ray nova, or a flaring magnetar might be observed with the XPOL, XMS, and HTRS in sequence. We therefore budget a small amount of time, 30ks or 0.1% of the year, for such events.

2.5 Engineering

Most engineering activities can take place during routine observations, but there will be occasional need to calibrate the gyros via long slews along the gyro axis. The aspect camera will also need occasional dark current calibrations. Chandra does these during perigee, 3 time per year for 4 hours each, but for IXO they may need to be done during time that could otherwise be used for science. We therefore budget 86ks, 0.3% of a year.

2.6 Momentum Management

Any offset in the center of solar pressure and center of mass in the observatory will cause momentum buildup in the reaction wheels, which will eventually need to be offloaded. The NASA approach uses a small thruster firing every 18 min, the ESA approach stores this momentum in the reaction wheels and offloads it every other day. Thruster firings must be small enough that they do not affect the stability of the observatory during observations. Large offloads of the reaction wheels can be done during slews. We therefore do not include an allocation in the budget for this item, but note that the stability during possible thruster firings must be monitored.

2.7 Other: Solar Flares

Both CXO and XMM experience sporadic high background intervals which in extreme cases require observations to cease in order to safe the instruments, and more often increase the background to the point where the data quality is lowered. XMM is more sensitive to these events, and over the first 5 years of observations 36% of all time showed enhanced background, and ~5% was completely lost due to the strongest flares [2]. These intervals are clearly associated with CMEs, and in addition they are enhanced when the spacecraft's orbit takes it between Earth's bowshock and mangetopuase. The frequency of CMEs is tied closely to the solar cycle and the number of active sunspots. While the solar-wind induced radiation environment at L2 is likely to be different that that seen by CXO and XMM, CMEs are still likely to have a strong effect and the IXO L2-Halo orbit traverses the magnetopause boundary, just like CXO and XMM. The IXO anticipated launch date of 2021 places it near the minimum of the solar cycle (see below), so we anticipate little time lost to this effect early on in the mission, but this might rise to ~5% five years later. We note that Herschel was launched 1 year ago to L2 and has a radiation monitor similar to that on XMM, and has seen no solar flares to date. We therefore budget 2.5% of the time to this item, which is expected to be the average over mission life.

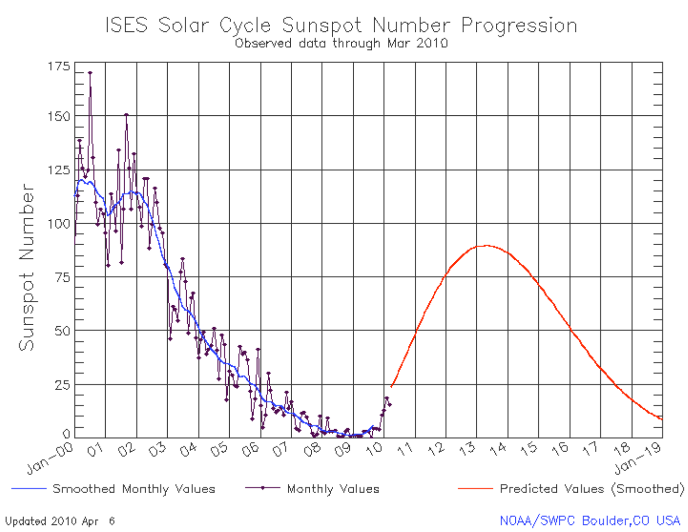

Figure 2: Observed and predicted sunspot number, from http://www.swpc.noaa.gov/SolarCycle/. IXO will launch near the minimum of this cycle, so should have very few radiation interrupts in the first few years of operations. However after 5 years of operations the interrupt rate could reach the 5% level seen by XMM at the peak of the solar cycle.

2.8 Impact of TOOs

TOOs reduce overall efficiency, as they require deviating from the optimal schedule of targets. The overall approach is described in detail in a paper by M. Santos-Lleo (2001; ESA Bulletin 107, p.54, http://xmm.esac.esa.int/external/xmm_sched/sched_tour/ESA_bulletin_107.pdf) which shows how XMM handles TOOs. P. Slane notes the following as regards CXO and TOOs (email 09-11-06; edited for brevity):

> *For CXO, both the timeline for generating schedules and the issue of TOO response are driven by the fact that we have limited contacts and no on-board decision-making regarding rescheduling. Since we operate in the blind for a minimum of 8 hours (and are required to configured to allow safe operation even if we miss one of the COMM passes - so 16 hours is really the requirement, I believe), the loads on board have to be bulletproof. Hence the long planning and review process.*
>
> *I don't know if the COMM schedule will be any more favorable for IXO. Even if it isn't, though, one can imagine building the spacecraft on-board software to provide more "smarts" in terms of operation. For example, one might have a catalog of targets on board, with a timeline for observation, and an instruction set that says "if I get a TOO interrupt from the ground, I go do that target, and while I'm doing it I figure out what the safe and optimal way of getting back to other observations is, using my list of targets and on-board capability to calculate sky visibility and maneuvers; I send that revised plan to the ground, where they can use it as input to devise a revised longer-term plan that will get sent back up in a few days."*

The current IXO requirements call for a TOO response time of 24 hours, and assumes approximately 12 TOOs per year.

Table 2: IXO Observing Efficiency Budget (One year of obseravtions)

	Time (ksec)	Fraction	Range	Assumptions:	
				700	targets/year
Good Time Observing	**26775**	**85.0%**		60	degrees between targets
General Science	24727	78.5%		1.5	deg/min slew rate
TOOs	472	1.5%		0.06	settling time (ksec)
Calibration (Astron Srcs)	1575	5.0%	2%(CXO) - 5%(XMM)		
Pointing	**1795**	**5.7%**	**4.4% - 8.4%**		
Slew Time	1669	5.3%	4% - 8%		
Settling	140	0.4%			
Momentum Management	0	0.0%	will always occur during slews		
Instrument Preparation	**47**	**0.2%**	**0.1% - 0.3%**		
MIP Translation	30	0.1%	will normally occur during slews, unless slew is too short		
Instrument Setup	17	0.05%	For XMS/ADR, 12.6ks-25.2ks		
Engineering	**86**	**0.3%**			
Command Upload	0	0.0%	Done during observations		
Calibrating Gyros/ACA	86	0.3%	Use 3@ cals/year, 4 hrs each		
Other	**976**	**3.1%**	**0.6% - 5.6%**		
Spacecraft	86	0.3%	One day/year for safe mode or other problems.		
Instruments	86	0.3%	One day/year for all instrument problems.		
Ground Station	0	0.0%			
Communication	0	0.0%			
Solar Flares	787	2.5%	0 - 5% based on XMM		
Eclipses	0	0.0%			
Spare Capability	**1795**	**5.7%**	**9.9% - 0.7%**		

3. Observing Plan Characteristics

As IXO will be a general-purpose observatory whose target list will be determined yearly by community input and a telescope time allocation committee, it is not possible to pre-determine the exact list, either by number of observations or their distribution on the sky.

However, we can make some predictions about the overall allocation of observations. ***The number of targets to be observed per year strongly impacts the observing efficiency.*** The SDT-approved list of targets for the core observatory science (see Table 3) contains 2931 sources over a 5-year period, or 586 observations/year, while leaving 17% of the time for observatory science. ***Assuming a similar rate for the observatory science time, we predict of ~700 observations per year for IXO.*** This agrees with experience from both CXO and XMM, which complete between 650-1100 scientifically usable observations per year. This includes all targets, both calibration and science, and includes multiple observations of a single target that were broken up due to orbital or thermal considerations or because of not fulfilling the approved time in the first instance.

Our estimate of 700 targets/year corresponds to an average observing time per target of 38 ksec. Since missions normally see a trend towards longer observations of fewer targets as they age, 700 targets/year is probably a lower bound for the early phase of the mission.

We can also estimate the target distribution on the plane of the sky. For example, by examining the proportions of targets in these categories for CXO and XMM we can estimate that ~10-15% by number will be in the Galactic plane (b<2 deg) and ~50% will be at high Galactic latitude (b > 30 deg). We also found that the percentage of time spent on Galactic plane targets with CXO is significantly less (only ~5%) than the percentage calculated by the number of targets (~15%). This is to be expected, as Galactic sources are generally brighter than non-Galactic and require shorter observing times.

4. A 12-month IXO Observing Plan

In order to carry out this study we need a target list for the first year of IXO observations. We have used the nominal list as described by obsplan_091124.xls, which is the baseline for the most recent studies (ie, ESA MRD V1.3, April 2010) with the following modifications in order to enhance fidelity:

1) NS EOS target list had been taken from all XMM targets in the category ‘NS’, but here we use only those classified as Bursters in the catalog from Liu et al [3]. Prime instrument is HTRS, total time 1.1Ms.
2) The Magnetar list is from the on-line catalog maintained by Vicky Kaspi at McGill.. Prime instrument is XPOL, total time is 0.7Ms. See: http://www.physics.mcgill.ca/~pulsar/magnetar/main.html
3) Stellar Mass black holes are from the on-line list maintained by Jerry Orosz at SDSU. Each object is observed with the XPOL and HTRS, total time is 1.8Ms. See: http://mintaka.sdsu.edu/faculty/orosz/web/
4) Strong Gravity targets are from the list described in IXO memo mrg-2010-02v2[4], which ultimately comes from an ASCA survey of bright AGN, many of which have measured Fe line strengths. Observing times for the lower mass objects were set to 10x orbital timescale at a few Rg, but for the more massive objects to the ~orbital timescale, and the list culled to limit the total time to 1.2Ms. Prime instrument is XMS.
5) The cluster cosmology targets had been taken from the SDSS, but this unrealistically puts them all in the same part of the sky. Instead we use clusters from the BAX catalog[5] with z>0.3. Prime instrument is WFI, total time is 2.8Ms.
6) Stellar flare targets are taken from the HEASARC flarestar catalog, Gersberg et al 1999[6]. Prime instrument is XMS, total time is 0.5Ms.
7) The SMBH Spin Survey targets were taken from the XMM observing list, category AGN, and herein ~1/3 of this list has been replaced with CDF/N and CDF/S targets in order to populate the list with a number of high-z

AGN, as suggested by the paper of Ballantyne 2010[7]. Total time is 1.9Ms, prime instruments are XMS and WFI (for CDF only).

The planetary disk targets are taken from the Ophiucus and Taurus star forming regions, XMS prime, 0.4Ms total. The remaining targets (cluster evolution, XMS and WFI, 2Ms; feedback, XMS, 1.6Ms; starbursts, XMS and WFI, 1.0Ms; cosmic web, XGS, 2.4Ms; deep surveys, WFI, 2.3Ms; formation of the elements, XMS, 1.0Ms; stellar atmospheres, XMS, 0.6Ms) were selected from the merged XMM target list, selecting based on the target categories in that list. Total number of targets in the list is 630, similar to the number of targets in a years worth of XMM or CXO observations. Total time is 23.5Ms, which assuming an observing efficiency of 85% leaves 12% of the year free for observatory science and calibrations. Approximately 7% of the time is devoted to HTRS observations, 5% to the XPOL, 32% to the WFI, and 44% to the XMS. This updated target list is known as ObsPlan_May15_2010.xlsx[8].

Table 3: IXO Core Science Observations, 5 year program

	Typical Targets	Average Obs. Length (ksec)	Total # of Obs	Total Obs. Time (Msec)
Matter Under Extreme Conditions				**16.5**
Strong Gravity	MCG-6-30-15	200	40	8.0
Neutron Star Equation of State	EXO0748-676, Sco X-1	32	170	5.5
QED Tests from Magnetars	SGR 1900+14	30	100	3.0
Black Hole Evolution				**27.4**
Deep Survey	CDF-S	300	38	11.4
SMBH Spin Survey	NGC 4051	50	200	10.0
Stellar-Mass Spin	Cyg X-1, GX339-4	50	120	6.0
Large Scale Structure				**49.0**
Cosmic Feedback from SMBHs	z= 0.02 - 0.1 cluster	200	20	4.0
Galaxy Cluster Evolution	z=0.1 - 2 cluster	80	188	15.0
Cosmology	z=1 cluster	10	1500	15.0
Cosmic Web of Baryons	QSO B1426+428	600	25	15.0
Life Cycles of Matter				**18.2**
Starburst Galaxies	NGC 3628, M82	50	100	5.0
Formation of the Elements	Tycho SNR	50	100	5.0
Stellar flares	hot star/cool star flares	50	50	2.5
Stellar atmospheres	AB Dor	50	50	2.5
Protoplanetary Disks	GY 238 in Ohiuchus	20	100	2.0

5. An example trade

The design of the IXO can be studied as a series of trades aiming to increase the science output of the mission. As an example of such a trade we study the relation between slew speed and science return in terms of a trade between mirror mass and reaction wheel mass. Higher reaction wheel mass would allow higher slew speeds and higher observing efficiency, but this mass ultimately would come out of the mirror and therefore decrease the telescope effective area. For some fraction of the IXO observing plan the science return can be quantified by the number of photons collected, and small changes in the effective area can be effectively balanced by an increase in observing time: a 1% decrease in effective area could be compensated by a 1% increase in observing time. For some (smaller) fraction, the observations are background limited and a 1% decrease in effective area could be compensated by a 2% increase in observing time. This is because in the BG limited case the S/N quantifies the science return and S/N ~ Area x sqrt(Time); note that we are assuming a small area change in this calculation.

Relevant quantities which are input to the study are the reaction wheel mass, the mirror mass, the time spent slewing, the range of slew rates likely to be achievable, and the relative fraction of the observing program which is BG limited vs. photon limited. The reaction wheel masses and slew rates will be taken from the NASA and ESA studies. The ESA studies have lighter wheels and slower rates than the NASA studies.

We assume the following parameters for the observatory:

1) Reaction wheel mass: NASA wheels ~107 kg, ESA ~50kg, and
2) Mirror Mass: Glass Mirrors FMA = 1731 kg

Observing plan: Using the observing plan described herein and making the cut between photon limited and S/N limited at 100ks average observation length, finds 70.7Ms 'photon limited' and 40.4Ms 'S/N limited'. Note that the photon limited pool includes 15Ms for galaxy cluster evolution with an average observing time of 80ks, which might reasonably be instead put in the S/N limited pool. Doing so would make the fraction 55.7Ms vs 55.4Ms, but the conclusion of this trade is unlikely to be strongly affected by either choice.

Given the likely reaction wheel mass, the maximum amount one might consider trading is 50kg. That is, take 50kg from the mirror and add it to the reaction wheel mass. We assume this will take the slew rate from 1 deg/min (the ESA study rate) to 2 deg/min (the NASA study rate). As noted above, given the study slew distance of 60 degrees, and a typical years observing program with 700 targets, the 1 degree/min slew rate uses 2.5Ms, the 2 degree/min rate 1.25Ms. Adding 50kg to the reaction wheels recovers 1.25Ms of observing time per year, or 3.98% of a year. We can therefore assume that each observation duration would be ~4.0% longer.

The 50kg is also 2.9% of the segmented-glass mirror mass, which we assume translates directly into a ~3% decrease in the mirror area. Therefore in the photon limited case, there is a science gain – the number of photons collected with 4% additional time, but 3% less area, is increased by 1%. For the BG limited case, there is a science loss – in order to compensate for the 3% decrease in area we need a 6% increase in observing time, and we only get a 4% increase in observing time. End result is a 1% decrease in the S/N.

If the observing plan is balanced, the trade considered above has essentially no impact on the science return. If the observing plan favors the photon limited case as seems likely, the trade suggests that the faster slew rate gives a slight benefit to the science return. We gain 1% on the 64% (70.7/111.1) of the time that is photon limited and lose 1% on the 36% of the time that is background limited, for a net gain of order 0.3%.

We note that we have studied the limiting case in which all of the additional mass needed for faster slewing comes directly out of the mirror. If some of this mass savings can be found in other s/c systems then the science gain due to faster slewing will be larger.

6. Conclusions

Based on the SDT generated science case and the prior examples of CXO and XMM, a plausible yearly observation plan should include ~700 separately pointed observations separated by slew lengths of ~60 degrees. The primary impacts on observing efficiency will likely be slew rate (4% - 8% of time available) and solar flares (0% - 5%). During solar minimum and assuming the moderate slew rates there is adequate margin (5.7%) to reach the 85% observation efficiency number. Assuming the slower slew rates and an active sun this study shows there would be a much smaller margin (0.7%) to the 85% efficiency requirements.

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